

Technical note

EVALUATION OF THREE ORGANIC SOIL EMENDATIONS ON CLAY SOIL FOR BLUEBERRY CULTIVAR USING CLUSTER INTERPOLATED SPATIAL MAPS

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RESUMEN

Evaluación de tres enmiendas de suelos orgánicos en el suelo de arcilla para el cultivar de arándano utilizando mapas espaciales interpolados de clúster. La agricultura orgánica es la medida agroambiental y alternativa agroecológica que resulta en una agricultura de valor agregado. Este estudio determinó a través de la interpolación del mapeo de análisis geoestadístico si las medidas orgánicas utilizadas fueron biointensivas, y se modificó el suelo para cumplir con los requisitos para el cultivar de arándano. El área de estudio fue un huerto de arándanos de 0.88 hectáreas, en el municipio de Cusihuriachi, Chihuahua, México, que había sido sometido a 3 tratamientos distintos de enmienda orgánica del suelo para camas elevadas: (t1) yeso y azufre, (t2) yeso, azufre y compost y (t3) yeso, azufre, compost y polvo de aserrín de pino. Veinticuatro muestras de suelo se tomaron de 0 a 30 centímetros en todo el huerto de las camas elevadas, 75 días después de la aplicación de los 3 tratamientos del suelo. Las técnicas de análisis de suelo se usaron para determinar el porcentaje de arcilla en el suelo, el pH del suelo, la cantidad de nitratos mg.kg^{-1}

ABSTRACT

Organic agriculture are the agri-environmental measures and agri-ecological alternatives which result in value-added agriculture. This study determined through interpolation of geostatistical analysis mapping if the organic measures were bio-intensive, modifying the soil to meet the requirements for the blueberry cultivar. The area of study was a blueberry orchard of 0.88 hectares, in the municipality of Cusihuriachi, Chihuahua, México, which had undergone three distinct organic soil emendation treatments to raised-beds: (t1) gypsum and sulfur, (t2) gypsum, sulfur and compost, and (t3) gypsum, sulfur, compost and pine saw dust. Twenty-four soil samples were taken at 0 to 30 centimeters throughout the orchard from the raised beds, 75 days after the application of the three soil treatments. Soil analysis techniques were used to determine percent of clay in soil, pH of soil, amount of nitrates mg.kg^{-1} of soil, and percent of organic material in soil. The geostatistical analysis was determined through groups of similarity and difference with cluster Ward grouping. With the results from the analysis of cluster Ward

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de suelo y el porcentaje de materia orgánica en el suelo. El análisis geoestadístico se determinó a través de grupos de similitud y diferencia con el agrupamiento Ward. Con los resultados del análisis del clúster Ward se generó un mapa interpolado para cada parámetro al utilizar ArcMap y la interpolación de ponderación de distancia inversa. La conclusión de este estudio fue que el mapeo de interpolación era una herramienta de visualización útil para determinar que no había diferencia ponderada entre los 3 tratamientos de enmienda y que ninguno de los tratamientos fue lo suficientemente efectivo como para emendar el suelo a las condiciones deseadas por el cultivar de arándano en los parámetros observados. Los mapas también fueron útiles para determinar las condiciones específicas del suelo, fuera del área de tratamiento, que podrían ser utilizadas por el productor para determinar un plan de gestión de agricultura de precisión, que podría considerarse como una medida agroambiental adicional.

INTRODUCTION

Sustainable agriculture is the implementation of techniques, such as precision agriculture, which preserve the environment without compromising actual levels of food production (Billib *et al.* 2009). Organic agriculture is the use of technologies in accordance with the socioeconomic and ecological conditions of the zone where a productive system is located (Valarini *et al.* 2009). It is imperative that the impact of organic agriculture management techniques, such as applying varying amounts of organic additive to an orchard, be evaluated so that appropriate practices can be developed and the risk of pollution from leaching of nutrients can be minimized (Billib *et al.* 2009). Descriptive statistics and geo-statistics are techniques for the elaboration of linear and spatial models of orchard conditions (Rodríguez-Vasquez *et al.*

an interpolated map was generated for each parameter using ArcMap and inverse distance weighting interpolation. The conclusion from this study was that interpolation mapping was a useful visualization tool, to determine that there was no weighted difference between the three emendation treatments, and that none of the treatments were effective enough to emendate the soil to the conditions desired by blueberry cultivar for the parameters observed. The maps were also helpful in determining specific soil conditions, outside of the treatment area, which could be utilized by the producer to determine a precision agriculture management plan, which could be considered as an additional agri-environmental measurement.

2008). The use of descriptive statistics allows identifying the existence of variability of soil attributes (Orjuela-Matta *et al.* 2012). Fertilization and soil emendation programs can be more precise, resulting in less waste and more control of soil conditions, when groups of soil conditions are identified and categorized (Orjuela-Matta *et al.* 2012). Normal techniques for determining soil attributes analysis, such as determining the coefficient of variation (C.V.) through dispersion, cannot determine the spatial variability of the soil, since this technique does not give information about the pattern of spatial distribution of a particular attributes (Orjuela-Matta *et al.* 2012). Simple geo-statistic techniques such as with cluster analysis allow visualizing the linear correlation of soil attributes in a detailed and practical manner, in order to facilitate the management of soil through the establishment of distinct

zones (Orjuela-Matta *et al.* 2012). Spatial distribution maps are used to identify spatial attribute changes (Dec *et al.* 2011). Spatial mapping is a tool which creates a visualization of the geostatistical analysis, by geo-referencing soil sampling points onto a map to thoroughly determine conditions of the soil, in order to design a management plan for each specific condition in a given area. Spatial maps that are georeferenced are useful in observing relationships of soil attributes in the area (Mandal & Sharma 2009). Interpolated spatial maps are generated through methods to estimate the values of a variable in an irregular two-dimensional array. Currently, there is no universal equation, or predictive model that can be applied to all geographic regions or purposes (Grunwald 2010). Estimation model decisions are subjective because the models are derived from the expert knowledge and a great deal of experience with soil mapping techniques and soil mapping programs (Walder *et al.* 2008). Digital soil maps interpolated using regression kriging are suitable for national planning (Taghizadeh-Mehrjardi *et al.* 2014) but there is a lack of fine detail needed to make specific evaluations (Walder *et al.* 2008). The amount of sample points required to make the interpolated maps useful for precision agriculture, is subjective to the purpose of the proposed study (Yang *et al.* 2013). Studies have shown a high variability of values, when comparing the same sample area, generated with a different number of points, resulting in an overestimation for the smaller sample size (Carvalho-Guedes *et al.* 2013). Studies suggest a low accuracy regarding the similarity between the maps generated for the estimated values depending on appropriate sample size and manner of equating the interpolation (De Bastiani *et al.* 2012), meaning a decrease in the reliability of the interpolated maps (Camacho-Tamayo *et al.* 2008). A study in Iran, using decision tree interpolation methods found an 86% accuracy, noting that depending on the soil classification there was a variation in the accuracy of the model (Taghizadeh-Mehrjardi *et al.* 2014), but other studies had showed validity of interpolated results could be

down to 67% (Jafari *et al.* 2012). Inclusions and the misplacement of boundaries are 2 problems associated with soil mapping which can result in erroneous maps (Qi and Zhu 2003).

The objective of this study was to generate interpolated spatial maps of soil attributes from groups of similarity and difference determines by Cluster Ward analysis, to evaluate an organic soil emendation program to determine both the effectiveness of each treatment and to determine soil condition zones. The soil texture, pH, nitrates (NO_3), and organic material (OM), were considered important edaphic parameters to measure considering the specific requirements for blueberry cultivar (Ferreya *et al.* 2001). Understanding the conditions of the soil with a spatial map by observing spatial attribute zones helps the producer to have control over soil management. This study also evaluated the usefulness of interpolated maps for small area, precision agriculture.

MATERIALS AND METHODS

Location of study area

The study was carried out in the municipality of Cusihuriachi, Chihuahua, México on a blueberry orchard referred to as “La Finca”, on the property of the “Grupo Norteña”. It was located at 2202 m.a.s.l., 28.06.53.6 N and 107.03.20.7 W.

Description of superficial area of the study

The total area of the study was 0.88 hectares divided into nine raised-beds. The raised beds were subjected to three different organic soil emendation programs. The first treatment (t1) was gypsum and elemental sulfur at 20 and 10 $\text{ton}\cdot\text{ha}^{-1}$, respectively. The second treatment (t2) was t1 plus 60 $\text{ton}\cdot\text{ha}^{-1}$ of compost. While the third treatment (t3) was t2 with the addition of 60 $\text{t}\cdot\text{ha}^{-1}$ saw dust. The treatments were applied to the raised bed at time of plantation of blueberry cultivar, each raised bed were subjected to all three treatments.

Soil sampling

The sampling was completed on Thursday, August 13, 2015, 75 days after the initial application of the treatments. A total of twenty-four samples were taken from four raised-beds; two samples from each treatment per each raised-bed. The depth of the sample was taken between 0-30 cm and approximately two kg of each sample was collected. Samples were then saved in plastic bags, where they were given the reference number. Each sample point was geo-referenced with a GPS (XT 300, Trimble, USA).

Soil analysis

The soil samples were dried at room temperature a 34 to 40°C. The variables evaluated in soil were clay by the hydrometer method (Medina 2007), NO₃ by the Brucine method and spectrophotometry (PerkinElmer Inc.) (Uvalle-Bueno 2000), organic material by Walkley-Black method (Uvalle-Bueno 2000), and pH in dilution 1:2.5 (w/v) in saline 0.01M CaCl₂ using potentiometer (AB15, Fisher Scientific, US) (Uvalle-Bueno 2000).

Geo-statistical analysis

The geo-statistical analysis was calculated on SAS/STAT program with cluster Ward to generate groups of similarity, at 0.5 r square partial correlation. The clusters set up the range that was used to classify the spatial groups for each soil attribute.

Cluster interpolated spatial maps were generating using ArcMap module. The spatial dependence of the attributes was analyzed by experimental variograms, and the nugget ratio was used for the classification of the spatial structure of the analyzed attributes (Lillesand *et al.* 2015). The geostatistical model, inverse distance weighting (IDW) was used for the interpolation on points. The interpolated spatial map of the raised-bed considered 24 points in an area of 0.88 hectares. The clusters found in the geo-statistical analysis Ward were the parameter groups used to define the areas of comparison.

RESULTS AND DISCUSSION

The resulting spatial maps are the visualization of the geostatistical analysis of four soil attributes: percent of clay in soil, the pH of soil, the amount of NO₃ in soil for mg.kg⁻¹ and the percentage of organic matter in the soil. These four edaphic parameters are considered paramount for the success of the blueberry cultivar (Eck *et al.* 1988, Caspersen *et al.* 2016). The IDW interpolation maps show distinct clusters set by considering the r-squared partial correlation parameters, at 0.5 similarity, and compare the success of each of the three soil emendations treatments at reaching the desired conditions determined ideal for blueberry cultivar.

Percent of clay in soil

It can be observed in Figure 1 that the 2 distinct groups of percent of clay range from 31 to 48 and 50 to 91 percent clay. Although, there are 2 distinct groups, the cluster of 50- 91% clay falls into the soil texture category of clay, while the other cluster was considered either sandy clay, or sandy clay loam. Soils with clay texture are considered difficult to cultivate in because of the array of problems associated with them such as problems with drainage, aeration, and compaction (Navarro-Garcia & Navarro-Garcia 2013). Gypsum does not have the same colloidal potential as clay particles but it forms a residue in soil that is the same particle size as clay, and therefore it can alter the soil texture (Navarro-Garcia and Navarro-Garcia 2013). The blueberry cultivar prefers light soils and have good drainage (Eck *et al.* 1988, Gou *et al.* 2012, Burkhardt *et al.* 2009, Caspersen *et al.* 2016). Heavy soils may be treated with high levels of organic matter, such as compost and saw dust (Burkhardt *et al.* 2009, Caspersen *et al.* 2016) to try to raise the organic material to more than 15% (Guzman 2007, Valarini *et al.* 2009), but these studies indicated on making the addition before the plantation of the cultivar.

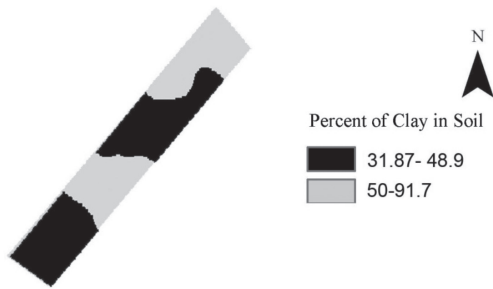


Fig. 1. Spatial map of the percentage of clay in the soil sampled from the raised beds using IDW interpolation method.

pH of soil

The 2 distinct groups determined for pH from cluster Ward groups were 4.6 to 5.3 and 5.8 to 6.4, Figure 2. The blueberry cultivar prefers a soil pH of 4.3 to 4.8, but may tolerate a pH as high as 5.2 (Eck *et al.* 1988, Van Breemen *et al.* 1983, Casperenet *et al.* 2016). Elemental Sulfur and gypsum was added to all three treatments to lower pH (Sierra *et al.* 2007) but did not successfully lower the pH uniformly, considering there were still clusters which were categorized as out of the range tolerated by the blueberry cultivar. According to Valarini *et al.* (2009) compost is not seen to lower pH in soil; in fact their results show an increase in pH with the addition of compost.

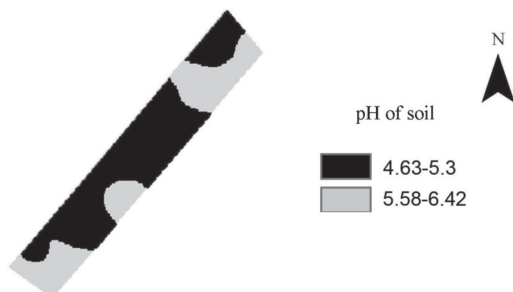


Fig. 2. Spatial map of pH in the soil sampled from the raised beds using IDW interpolation method.

NO₃ in soil

The 2 distinct groups calculated to visualize NO₃ in soil from the cluster Ward were 1.32 to 7.77, and 10.29 to 26.91 mg.k⁻¹, Figure 3. It is recommended that the blueberry cultivar needs 20-140 kg.ha⁻¹ a year (Hanson 2006) or 17-26 g of N per plant each year for the first 4 years after plantation (Bryla & Machado 2011). Although 2 different clusters were determined, the spatial maps does show that the distribution of NO₃ is very uniform, considering that treatment 1 had no emendation which would have added to the content of N in the soil. It has been found the available nitrogen (N) is increased with the addition of compost (Valarini *et al.* 2009), but that when added as a top dressing, some of the available nitrogen might be immobilized by microorganisms in the soil (Finn and Warmund 1997). It also has been noted, that the addition of saw dust will not immediately alter the values of N (Sandoval *et al.* 2012).

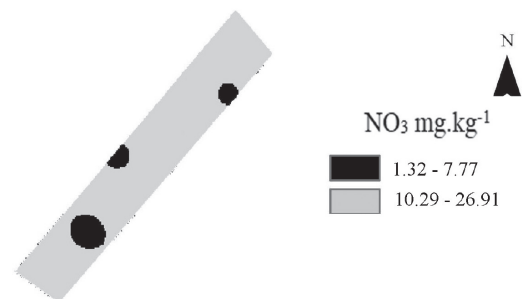


Fig. 3. Spatial map of NO₃ mg.kg⁻¹ in the soil sampled from the raised beds using IDW interpolation method.

Percent of organic matter in the soil

The 2 distinct groups calculated to visualize the percentage of organic material in soil from the cluster Ward were 1.3-1.97% and 2.06- 2.89%, Figure 4. The blueberry cultivar requires a high content of soil organic material, in general higher than 10% (Caspersen *et al.* 2016), but when grows

in heavy soils, such a soils high in the context of clay, that requirement may be as great as 15% (Burkhard *et al.* 2009, Guzman 2007, Valarini *et al.* 2009, Echeverria *et al.* 2009). Although, there are clusters of grouping of organic matter, all samples fall significantly lower than the requirements of the blueberry cultivar. Compost and saw dust added to soil increases the percentage of organic matter in the soil and improves clay soils, physically, chemically and biologically (Navarro-Garcia & Navarro- Garcia 2013, Komilis & Tziouvaras 2009, Burkhard *et al.* 2009). Studies have indicated that improving organic material percent in soil for more than 10% requires a large investment (Caspersen *et al.* 2016).

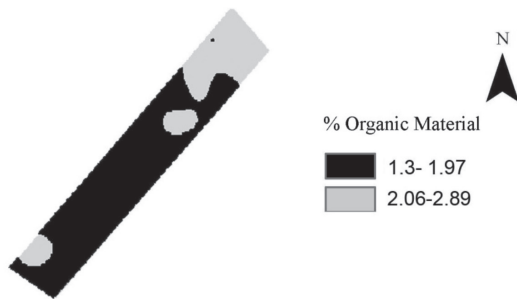


Fig. 4. Spatial map of percent of organic material in the soil sampled from the raised beds using IDW interpolation method.

CONCLUSION

Spatial mapping is a useful tool for the visualization of the results of a geostatistical analysis of soil samples. Maps made from the interpolation of points determined the zones of similar soil which determine the effectiveness of the soil emendation treatments. Considering the edaphic parameters evaluated in this study, soil texture, pH, NO_3 , and organic matter, none of the treatments modified the soil enough to meet the requirements for the blueberry cultivar. The analysis of the spatial mapping made it apparent, that the majority of planted surface area needs to be emended to realize the soil conditions required by the blueberry cultivar, and the producer must

consider the social and environmental cost and determine if by continuing with the soil management would still meet the criteria determined to be organic crop management.

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